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THERMAL FLUX AND AN ESTIMATE OF THE COEFFICIENT OF HELIUM RELEASE FROM THE EARTH'S CRUST INTO THE ATMOSPHERE

Yu.P. Bulashevich

Translation of "Teplovoy potok i otsenka koeffitsienta vydeleniya geliya Zemnoy koroy v atmosferu," Doklady Akademii Nauk SSSR, Vol. 212, Oct. 1, 1973, pp. 854-855,

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16. Abstract

Studies of the coefficient of helium release into the atmosphere from the Earth's crust have been made previously, and are based on the gas dynamics in the upper layers of the atmosphere. This coefficient is equal to the ratio of the escape rate to the generation rate of He^2 in the Earth's crust and upper mantle. Formulas are given based on previous calculations, for defining the coefficient of helium release more exactly. However, further development of a thermal model of the Earth is still required.

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THERMAL FLUX AND AN ESTIMATE OF THE COEFFICIENT OF HELIUM RELEASE FROM THE EARTH'S CRUST INTO THE ATMOSPHERE

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1. Heat and He^4 are produced when uranium and thorium decay in the Earth's crust. Additional heat is caused by decay of K^{40} with the formation of Ar^{40} and calcium. Obviously, there must be a link between the thermal flux and fluxes of stable radiogenic gases, caused by the unity of sources and the analogy of propagation processes (thermal conductivity, diffusion and convection). /854*

Some of the helium and argon remains in grains of rock, and some is released and migrates towards the Earth's surface, afterwards arriving in the atmosphere, especially in fracture areas [1-3], argon accumulates in the atmosphere, and helium is given off into space. It is assumed that there is an equilibrium between the dissipation of helium and its emergence from the Earth's crust into the atmosphere [4]. There are numerous evaluations for the escape rate of He^4 into space, based on gas dynamics in the upper layers of the atmosphere [4]. This determines the possible limits of the coefficient of helium release from the Earth's crust into the atmosphere.

The release coefficient equals the ratio of escape rate to the generation rate of He^4 in the Earth's crust and on its mantle; for this calculation one needs to know the absolute amount of U^{238} determining the He^4 flux. However, it is preferable not to use absolute values. The coefficient of the release of He^4 can be obtained by comparing the ratio of escape rate and the observed geothermal flux with the ratio of the generation rates of helium and heat in the Earth's crust and on

*Numbers in the margin indicate pagination in the foreign text.

its mantle. We are calculating on the assumption of the quasi-stationary nature of thermal fluxes and He^4. The quasi-stationary nature is understood as the short duration of relaxation for thermal and gaseous heterogeneities for a layer of the Earth's crust and its mantle, in comparison with the average life duration of sources. This is by no means the best approximation, but is permissible for sources in the Earth's crust [5]. The mean grid density of the continental and oceanic heat flux is practically identical [6]. As for the smaller strength and radioactivity of the oceanic crust, the upper mantle below it should contain higher concentrations of radioactive elements than the mantle below continents [7]. In this way, one and the same amount of radioactive elements is distributed, probably in layers of different strengths. Apparently, thermal transfer in the upper mantle is equivalent to the quasi-stationary nature of processes for corresponding depths.

2. The mean grid density value of a thermal flux for the whole Earth is $j = (1.43 \pm 0.75)$ cal/(cm^2·sec) [6, 7]. Hence, for the global flux we obtain $Q_H = 2.22 \cdot 10^{20}$ cal/year. The thermal generation rate equals:

$$Q = \left(a_U \lambda_U + a_{Th} \lambda_{Th} \frac{Th^{232}}{U^{238}} + a_K \lambda_K \frac{K^{40}}{U^{238}} \right) U^{238}, \tag{1}$$

where $a_U = 18 \cdot 10^{-13}$; $a_{Th} = 15 \cdot 10^{-13}$; $a_K = 0.27 \cdot 10^{-13}$ in calories per disintegration [8] on the assumption of secular equilibrium among uranium and thorium, λ are the corresponding constants of decay. U^{238}, Th^{232}, K^{40} is the amount of atoms in the Earth's crust /855 and on its upper mantle, providing the observed thermal flux. For the weight concentrations of these elements we shall accept values according to [9]: $n_U = 3 \cdot 10^{-4}\%$, $n_{Th} = 8 \cdot 10^{-4}\%$; $K^{40} = 3.1 \cdot 10^{-4}\%$. With these values, according to (1) we obtain $Q = 59.6 \cdot 10^{-23} \cdot U^{238}$ calories/year.

3. The formation rate of He^4 is determined by the expression:

$$p = \left(8\lambda_U + 6\lambda_{Th} \frac{Th^{232}}{U^{238}}\right) U^{238}, \tag{2}$$

or $p = 20.5 \cdot 10^{-10}\ U^{238}$.

For He^4 flux into the atmosphere we have:

$$q = \alpha \cdot p = 20.5 \cdot 10^{-10}\ \alpha U^{238}, \tag{3}$$

where α is the coefficient of helium release from the Earth's crust into the atmosphere.

4. Evaluating the flux of He^4 from the surface of continents and oceans into the atmosphere is done in indirect form by the escape rate into space (a review of some information is available in [4]). In one of these works, the dissipation rate q_H is calculated with regard to the ionization of helium and the effects of the geomagnetic field [10]. In this case, escape takes place in polar regions of the magnetosphere and $q_H = (6.6\text{–}13.2) \cdot 10^{31}$ technical atmospheres per year. An approximate determination by measuring the concentration gradient of He^4 through small apertures gave, for one of the granite land masses in the Southern Urals, $q_H = 13 \cdot 10^{31}$ technical atmospheres per year [1], which coincides well with the dissipation flux shown above.

5. Assuming that $q/Q = q_H/Q_H$ and using (1)-(3), we find:

$$\alpha = \frac{q_H}{Q_H} \frac{a_U\lambda_U + a_{Th}\lambda_{Th}\, Th^{232}/U^{238} + a_K\lambda_K\, K^{40}/U^{238}}{8\lambda_U + 6\lambda_{Th}\, Th^{232}/U^{238}} \tag{4}$$

Let us call $q_H = n \cdot 10^{31}$ technical atmospheres per year. By substituting this and other numerical values into (4), we obtain:

$$\alpha \approx 1.25n \cdot 10^{-2} = 1.25 \cdot n\,\%. \quad (5)$$

In the majority of articles on the dissipation of He^4, n is included in the limits of $13.2 \geq n \geq 1.1$ [10, 11]. Hence, for the coefficient of release of He^4 into the atmosphere we have $16.5 \geq \alpha \geq 1.4$. All these values are possible. The mean value is $\alpha \sim 9\%$.

Two methods are used for defining more exactly the coefficient of helium release into the atmosphere:

1) Experimental determination of the flux density of He^4 in the surface layer above the ground water level. This method is similar to determining the geothermal flux.

2) Research into the distribution of He^4 in the upper atmosphere and the increase in the validity of determining the dissipation flux. Of course, apart from this further development must be done of the thermal model of the Earth. Possibly, the cycle of operation of the melting of the upper mantle [12] caused the cycle of operation for the release of radiogenic gases, which is significant for understanding the high concentration of Ar^{40} in the atmosphere.

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